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Design Approach for Regional Sediment Management

by David S. Biedenharn

PURPOSE. The purpose of this Coastal and Hydraulics Engineering Technical Note (CHETN) is to describe the systematic approach to Regional Sediment Management (RSM) that has been developed as part of the Demonstration Erosion Control (DEC) project. Although developed specifically for the watersheds within the DEC project area of north and central Mississippi, the approach has application for stream systems throughout the United States.

BACKGROUND. There are numerous analytical and numerical tools available for addressing sediment transport processes, ranging from simple empirical approaches to more complex multidimensional sediment transport modeling. However, there is only limited guidance available on how to apply these tools in the development of plans to manage sediment throughout an entire watershed. In recent years there have been several approaches published that attempt to incorporate the entire watershed into the sediment management process. These include the watershed baseline survey approach by Downs and Thorne (1998), the fluvial audit by Sear et al. (1995), the river styles approach by Brierley and Fryirs (2000), and the fluvial hydrosystem concept by Petts and Amoros (1996). While these approaches represent important advances in the field of geomorphology and sediment management, specific guidance for their application is limited. A recent report by the US Army Engineer Research and Development Center (ERDC) (Copeland et al. 2001) outlines an approach to the hydraulic design of stream restoration projects. The design methodology is systematic. It is based on sound physical principles with sediment continuity being the cornerstone of this approach and, consequently, represents the state-of-the-art in channel restoration design. Although this approach focuses on maintaining sediment continuity, it is generally focused at the reach level and is not intended as a guide for the development of regional sediment management plans throughout an entire watershed.

Perhaps the most comprehensive and focused attempt to address regional sediment management is the US Army Corps of Engineers' DEC project. The DEC project seeks to develop and demonstrate a watershed approach to address problems associated with watershed instability: (1) erosion, (2) sedimentation, (3) flooding, and (4) environmental degradation. Initiated in 1984, DEC activities have been targeted at 16 watersheds comprising 6,800 sq km within the Yazoo River Basin in the Lower Mississippi Valley.

The DEC project provides for the development of channel rehabilitation features to control the interrelated problems of erosion, sedimentation, flooding, and environmental degradation. In contrast to channel restoration, which refers to restoring a resource to some former condition, channel rehabilitation is defined herein as maximizing the potential beneficial uses of a resource to some reasonable and practical level. The cornerstone of channel rehabilitation in the DEC project is effective regional sediment management. One of the key objectives of the project is to demonstrate methods for reducing sediment loads from the watersheds to downstream flood-control projects, reservoirs, and wetland areas. Thus, the DEC project represents one of the first true efforts to manage sediment on a regional basis. Typical features that are being used to

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achieve the project objectives include grade control structures, reservoirs, bank stabilization measures, channel restoration, and pipe drop structures to prevent gully formation. Other features being employed include levees, pumping plants, and land treatments. This project also includes long-term monitoring of the performance of constructed features, overall system response of channel rehabilitation measured in sediment yield reduction, and monitoring of habitat enhancement. The success of the DEC project can be documented by the long-term monitoring reaches. For instance, it has been estimated that between 50 and 75% of long-term sediment yield reductions are due to rehabilitation features (Watson et al. 2001). The DEC project is currently focusing on the relative influence of various rehabilitation features (bank stabilization, grade control structures, drop pipes, land treatments, etc.) on short- and long-term reductions in sediment yields.

OBJECTIVES. Regional sediment management is the key to providing long-term sustainable channel systems. A generalized systematic approach to regional sediment management is needed to address the large variety of projects that may range from localized erosion problems that can be addressed using a simple reference reach methodology, to severe basin-wide problems that require a concentrated analysis and design effort. The objectives of this technical note are to outline the DEC approach to regional sediment management.

DEC APPROACH TO REGIONAL SEDIMENT MANAGEMENT. Through the DEC project, a systematic approach to regional sediment management within a watershed context has been developed. This approach covers the entire life cycle of the project from the initial planning efforts to design, implementation, and monitoring. The planning aspects of this approach generally conform to the Corps' planning process (Orth and Yoe 1997) with an emphasis on solving regional watershed and channel problems. The basic components of the approach include: (1) project initiation, (2) geomorphic assessment, (3) plan formulation, (4) plan evaluation and preliminary design, (5) plan selection, (6) implementation, and (7) monitoring and feedback. A brief discussion of each of these elements follows.

Project Initiation. The initiation of the project must include organization of a team, identification of problems and opportunities, establishment of goals, and identification of constraints. The team members must comprise a group who are knowledgeable of the potential beneficial uses of the site, and of the techniques and costs associated with sediment management. Potential team members might include biologists, geomorphologists, engineers, recreation specialists, and representatives of the adjacent landowners and the community.

The number of team members should be as small as reasonably possible, but can be expanded as a viable project is identified and consideration of additional factors is necessary. For example, the initial team may be technically oriented in geology, biology, and engineering. As economic and social factors become relevant, additional members of the community and local government are essential.

Establishment of project objectives is a critical element during the initiation phase of the project. Probably the most certain path to an unsuccessful project is to fail to set a clear statement of the objectives of the project. Objectives provide the measure of success, and without unambiguous, measurable objectives, the project cannot succeed.

Geomorphic Assessment. The basic concepts of fluvial geomorphology and river mechanics provide the foundation upon which regional sediment management must be based. These concepts are incorporated into the design phase through a geomorphic assessment of the watershed. Unfortunately, many engineers fail to fully appreciate the importance of geomorphic analyses, or struggle with integration of the analyses into the design process. Many projects have failed, not as the result of deficient hydraulic or structural design, but rather through the failure to integrate the project with the morphology of the channel system. These types of problems can be minimized or in some cases eliminated by linking the comprehensive geomorphic assessment with the design process. The geomorphic assessment provides the physical process-based framework to define past and present watershed dynamics, develop integrated solutions, and assess the consequences of remedial actions. This is an essential part of the design process, whether planning a local bank protection project, habitat enhancement or attempting to develop a comprehensive plan for an entire watershed. The steps in a geomorphic assessment vary with the project objectives, authority, channel and watershed characteristics, and available resources. Although there is no “cookbook” approach, a typical geomorphic assessment would involve some form of the following: (1) data assembly, (2) field investigations, (3) data analysis, and (4) integration of results. It is beyond the scope of this technical note to fully describe the geomorphic assessment process. For more detailed information on conducting geomorphic assessments refer to Biedenharn et al. (1997) and Thorne (1998).

Plan Formulation. Once the geomorphic assessment of the watershed is complete, alternative plans should be developed. Alternatives can be either a combination of structural features such as grade control structures, channel improvement, levees, dams, bank stabilization, drop pipes (for gully control), vegetative barrier strips, or other measures. Nonstructural solutions such as land treatment management should also be considered in the plan formulation process. The product at the end of the plan formulation phase is an array of possible alternatives that address project objectives.

Plan Evaluation and Preliminary Design. At this point in the process, objectives have been established, potential alternatives have been considered, and a thorough understanding of the physical processes in the watershed has been developed. The next step is the evaluation of the plans and the development of a preliminary design. The plan evaluation and preliminary design process will ultimately resolve the question: “Are project objectives met?” Figure 1 provides an outline of the sequence of events for the plan evaluation and preliminary design. A brief discussion of each of the elements in Figure 1 follows.

Whenever a regional sediment management project is contemplated, one of the first issues that must be addressed is the overall stability of the channel system being considered. Failure to consider the system stability frequently results in costly channel designs that fail to function properly, both from an engineering and environmental perspective. The determination of the stability of the channel system is accomplished through the geomorphic assessment. If the project objectives are simply the stabilization of localized instabilities, or the installation of localized habitat features, then it is important that system instability does not exist. If it is determined that system instabilities do not exist, then the design of the local bank stabilization or habitat features can proceed. However, if system instabilities do exist in the form of aggradation, degradation, or planform changes, then it becomes necessary to first address these system

instabilities before local stabilization is considered. Likewise, if the system is currently in dynamic equilibrium, but it is anticipated that the project will modify this stability through changes in water and sediment yield, planform, or grade, then a more rigorous analysis must be performed. For this reason the first step in the design sequence shown in Figure 1 asks a critical question: “Does system instability exist or do project objectives require modified discharge, sediment yield, planform, or channel grade?” If the answer to all elements of the question is “No,” then the project may require only localized treatments such as local bank stabilization or local habitat enhancement features, and the design process moves on to Step 7 (Figure 1). However, if the answer to any of the elements of the question is “Yes,” then a five-step procedure with a feedback loop is required (Figure 1).

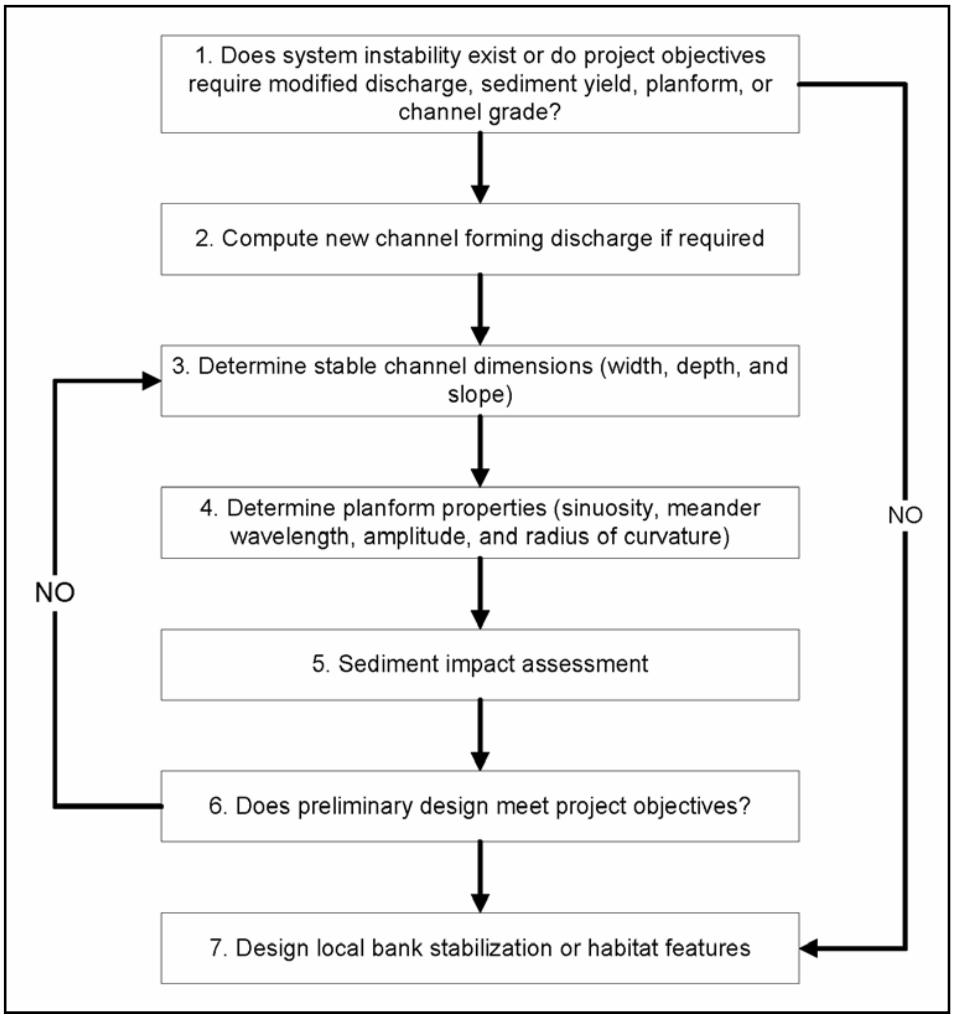

Figure 1. Plan evaluation, and preliminary design sequence.

The second step in the plan evaluation and preliminary design sequence is the determination of the channel forming discharge, which is often used in the initial calculation of stable channel dimensions. The channel forming discharge may be calculated by one of three methods described by Biedenharn et al. (2001): (1) bank-full discharge, (2) flow of a given recurrence interval, and (3) effective discharge calculation. If the project objectives will not significantly modify the water and sediment yield, then the existing channel forming discharge calculated during the

geomorphic assessment can be used for the design process. For example, if the objectives of the project are to simply stabilize the channel grade, and if low drop grade control structures are selected, then it may not be necessary to calculate a new post-project channel forming discharge, since the effect of these structures would not be expected to dramatically change the water and sediment loads. However, if the plan involves more comprehensive features such as flow control, channel enlargement, flow diversions, or other improvements that would significantly alter the post-project water and sediment loads, then it may be necessary to calculate a new channel forming discharge. The new post-project channel forming discharge is used in the determination of the stable channel dimensions discussed in the next step.

Computation of stable channel dimensions (width, depth, and slope) is the third step in the process and can be accomplished with a number of channel design methods (Figure 1). The selection of the appropriate method is a function of a number of factors such as level of study (reconnaissance, feasibility, detailed design, etc.), funding and time constraints, complexity of project and stream characteristics, consequences of failure of the design, and available data. For instance, during early reconnaissance studies, it may be appropriate to use some of the less computationally intense empirical methods (regime, hydraulic geometry, etc.). However, as the level of study increases, it might be necessary to conduct more rigorous analyses using numerical methods. While these procedures address more fully the dominant processes in the channel system, it must be recognized that the data requirements may also be more intensive. It should also be noted that in some situations it may not be necessary to calculate all three variables. For example, if the plan simply calls for the layout of a series of grade control structures to stabilize the channel, then it may only be necessary to calculate a stable slope to be used in spacing the structures. Regardless of the techniques used, the required product of this step is a channel design that meets project objectives without violating channel stability, particularly with respect to sediment continuity.

In some instances, the project objectives may require modification of the existing planform. When this occurs, the meander planform properties must be designed to be compatible with the stable channel dimensions calculated in the previous step (Figure 1). Copeland et al. (2001) provides a detailed discussion of several methods for calculating planform dimensions.

At this point, a word of caution is needed about re-establishing meanders in a previously straightened reach. While this is generally a commendable goal and one that may be achievable in certain circumstances, it is usually not as simple as is often purported, particularly in large-scale projects or where severe system instability exists or has existed in the past. For this reason, it is important to consider the stability of the reaches immediately upstream and downstream of the project reach. This is an essential yet often overlooked component of the design process. If the unstable project reach is bounded on the upstream and downstream ends by stable reaches, or if there exist some sort of man-made or geologic controls on both ends of the reach, then the reach may be much more manageable. Consider the example of a channel reach that is undergoing significant channel widening and has been converted from a meandering to a braided channel due to overgrazing along the reach. If the channel upstream and downstream of this reach is stable, then elimination of the overgrazing problem and the re-establishment of the old meander pattern may be a sustainable solution. Now, however, consider a project where the objective is to restore an 8-km (5-mile) segment of a 32-km (20-mile) straightened reach that has experienced 4.6 m (15 ft) of degradation. Several approaches could be identified to meet project

objectives, but each would have inherent problems. For example, simply constructing a new sinuous channel at the existing channel elevation would not re-establish the natural hydraulic connection between the channel and the floodplain. This problem could be overcome by abandoning the old channel and constructing a new channel in the floodplain. However, transitioning into the downstream reach would pose a serious problem that probably would require expensive and possibly environmentally unacceptable grade control structures to drop the flow from the new channel into the old channel.

The fifth step in the process is the completion of a sediment impact assessment (Figure 1). The purpose of the sediment impact assessment is to assess the long-term stability of the restored reach in terms of aggradation and/or degradation. This can be accomplished using a sediment budget approach (Copeland et al. 2001) for relatively simple projects or by the use of numerical models that incorporate periods of record sediment routings for more complex projects.

The next step in the process is the evaluation of the plan to insure that project objectives such as reducing sediment loads, flood control, erosion control, or environmental enhancements are met. If these objectives are not met, the design process returns to Step 3 to modify the design to ensure that the project objectives are met (Figure 1). Once a satisfactory design has been achieved that meets project objectives and provide long-term channel stability, then local bank stabilization or habitat features can be incorporated into the design (Figure 1).

Plan Selection. Once the alternative plans have been evaluated, the next step is to compare the plans and choose the best plan. The Corps planning process provides the basis for plan comparison and selection (Orth and Yoe 1997).

Implementation. The major elements included in implementation are detailed engineering design, construction, and inspection. Detailed engineering design would include, for example, computations of riprap size, structural design of drop structures, design of safety features, or other specific details requiring engineering design and construction drawings. Construction and inspection are not included in this technical note, but are generally included in standard guidelines provided by the agency funding the project.

Monitoring and Feedback. Too often monitoring has become just measurements with no real evaluation of the data or application of an evaluation in the feedback loop. Feedback is an essential part of monitoring. Monitoring and feedback of the performance data for stream rehabilitation features is essential for establishing requirements for maintenance and repair of features, performance of the measures, and for providing an essential feedback loop to planning and design of future projects. Major watershed and stream rehabilitation projects may require several years to complete all components, and monitoring results of the earlier constructed portions of the project can be used to improve the later portions of the project.

SUMMARY. The key to successful channel rehabilitation is effective regional sediment management. Failure to incorporate regional sediment management into the channel rehabilitation process often leads to more costly and less effective features, and increased maintenance cost over the life of the project. Therefore, it is critical during the design phase to identify the evolutionary trends in the watershed and to select rehabilitation measures that

compliment the morphologic processes and sediment transport throughout the watershed. The approach discussed in this technical note provides general guidance for designing channel systems within an effective regional sediment management context.

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Questions regarding this CHETN may be addressed to:

Dr. David S. Biedenharn	David.S.Biedenharn@usace.army.mil
Linda S. Lillycrop (RSM Program Manager)	Linda.S.Lillycrop@usace.army.mil

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